Use of Curve Advisory Speed Signs in New Zealand

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Abstract/Summary
The use of curve advisory speed signs in New Zealand was investigated. Traffic behaviour at the location of curve advisory speed signs was observed to determine the effectiveness of and compliance with current practice. Alternative methods for determining curve advisory speeds, using road geometry data or accelerometer-based systems, were compared with ball-bank surveys. The existing criteria and methods used for setting curve advisory speeds in New Zealand were assessed in light of the above findings and changes suggested. The field surveys found that the current ball-bank criteria underestimated observed mean speeds. A revised ball-bank relationship that did not take vehicle speed into account resulted in a much better fit. Allowing the use of alternative advisory speed methods is also recommended.

Notation

b_T	=	Ball-bank angle (degrees) at test speed
b_A	=	Ball-bank angle (degrees) at advisory speed
V_T	=	Test speed (km/h)
V_A	=	Curve advisory speed (km/h)

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Introduction
Although being a comparatively developed country, New Zealand has both a low population density and relatively difficult terrain. As a result, major roading expenditure is limited and the country continues to rely largely on two-lane highways of varying standard to link the major urban areas and access rural centres. Therefore, New Zealand highways often contain many sub-standard curves out of character with the surrounding environment that need to be identified and ultimately remedied.

As an interim safety measure, curve warning signs are erected to indicate the direction and severity of the following curve(s). In many cases a supplementary plate that shows a suggested “advisory speed” for travelling the curve(s) is also displayed. In New Zealand this is usually a speed ending in five between 15 and 95 km/h.

This paper presents findings of research undertaken to investigate the use of curve advisory speed signs in New Zealand (Koorey *et al*,1). In particular, the research considered both the instigation of these signs and their subsequent effects. The research set out to resolve two key questions:

1. Are the existing advisory speed criteria appropriate or do they need changing? If an updated method is considered necessary, there will also be the question of how the transition could be safely implemented.
2. Irrespective of the first question, are there more reliable and robust ways of determining/validating advisory speeds other than the existing ball-bank criteria?

The specific objectives for the research, which involved field and desktop studies, were to:

- Study the current traffic behaviour at the location of curve advisory speed signs in New Zealand to determine effectiveness and compliance.
- Assess the feasibility of using an alternative method to the ball-bank indicator for determining curve advisory speeds, e.g. road geometry data or accelerometer-based systems.
- Assess the existing ball-bank criteria used for setting curve advisory speeds in New Zealand in light of the above findings.

Although the research was quite wide-ranging, this paper will focus on the field surveys relating to the current ball-bank criteria.

Ball-bank and Alternative Surveys
In common with many countries, New Zealand relies on a “ball-bank indicator” (or “side-thrust gauge”) as the standard way of determining the need for and appropriate value of advisory speeds. A steel ball sealed in a curved glass tube is free to roll transversely under the influence of the forces acting upon it. The glass tube is graduated from a centre zero point outward to the ends of the tube in degrees of a full circle. When the vehicle traverses a curved path, the centrifugal force on the vehicle will cause the ball to roll out to a fixed position. The

ball-bank reading in degrees is the sum of the centrifugal force angle plus the body roll minus the superelevation angle. It is a measure therefore of the difference between centrifugal and gravitational forces on the vehicle and driver.

Some literature on the subject (Merritt, 2) suggests that the existing ball-bank criteria used in setting curve advisory speed have essentially not changed in over 50 years. Certainly, New Zealand's original system dates back to local trials carried out in the 1950's (Palmer, 3). In 1992, with the introduction of international symbolic road signs, the criteria was reviewed and a slightly less conservative policy, based on the New South Wales standard, was adopted (Jackett, 4). However the NSW relationship does not appear to be based on anything more recent than surveys in the 1970s (Preisler *et al*, 5).

In New Zealand, a linear equation is derived for the relationship between the ball-bank reading, b_A (degrees), and the true curve advisory speed, V_A (km/h):

$$b_A = 20.4 - 0.125V_A \qquad (1)$$

This equation is also used in New South Wales, and differs slightly from the Australian standard equation of:

$$b_A = 17.5 - 0.1V_A \qquad (2)$$

The above relationship alone could be used to determine advisory speeds by carrying out a series of test runs at different speeds until the test speed produced the correct relationship with b_A, at which point the true advisory speed would be known. However Preisler *et al* (5) found that a more efficient technique can be achieved by noting the following relationship:

$$\frac{b_T - K}{b_A - K} = \frac{V_T^2}{V_A^2} \qquad (3)$$

where

K = Constant for effect of superelevation and body roll, usually taken as 3°

The two equations can then be combined to form a quadratic equation in terms of V_A and solved. For example, the New Zealand / NSW ball-bank relationship produces the following formula:

$$V_A = \frac{V_T\left(\sqrt{V_T^2 + 6000(b_T - 3)} - V_T\right)}{16(b_T - 3)} \qquad (4)$$

In comparison with other US and Australian standards, New Zealand's current criteria for determining curve advisory speeds appear to be relatively less conservative; yet evidence suggests that drivers are still travelling notably faster than the posted speeds. A number of studies both locally and overseas have found fairly low compliance with the posted advisory speeds, with the majority of vehicles often not even complying within 10 km/h. (Chowdhury, 6; LTSA, 7). These findings led the researchers to question the current relevance of the existing criteria for setting advisory speeds. Drivers may be setting their speeds to the perceived road conditions, rather than accounting for the posted advisory speed. It needs to be noted however, that comfort rather than safety is generally used as the basis for setting advisory speeds - the implications of this need to be considered.

The mechanical nature of the ball-bank indicator also brings into question its reliability for assessing curve advisory speeds. Donald (8) and McLean (9) identified poor repeatability at varying test speeds, imprecise measurement by observation and equipment errors or biases as leading contributors to the inconsistency of posted advisory speeds.

Road geometry data and electronic accelerometers are now readily available and may be practical as alternative methods for establishing and reviewing curve advisory speeds. On New Zealand State Highways for example, regularly collected data is available at 10m intervals for:

- horizontal curvature (expressed as radius or 1/radius),
- longitudinal gradient,
- superelevation or crossfall

Combining these data with the design value for side friction (f), it is possible to calculate the design speed of a road section. Using this relationship the road geometry data can be used to generate a speed measure over the State Highway network. This approach is specified as an alternative method for determining curve advisory speeds in Australia (Standards Australia, 10) and has been used with reasonable success in New Zealand studies (Opus, 11).

Various commercially available devices have been touted as "hi-tech" alternative methods for determining suitable curve speeds. Generally these devices incorporate accelerometers to determine the forces acting on the vehicle carrying them, and on that basis derive suitable speed measures. The key advantage of such devices over manual ball-bank methods would appear to be accuracy in recording the correct lateral forces at the actual driven speed, rather than relying on observation for both of these measures. However, their adoption to date has been limited because of their much higher purchase cost when compared to the conventional ball-bank indicator.

Methods

Site surveys were conducted at curves both with and without advisory speed signs. The effectiveness of advisory speeds was checked by comparing them with actual vehicle speed profiles through the curve. Ball-bank tests were also carried out at each site to assess the true theoretical curve speed. Other relevant site data was also noted to determine any localised effects.

Traditional physical speed surveys using tubes or wires were likely to be problematic, due to damage from the braking and turning of vehicles through the curve. Radar-gun observation surveys would prove difficult to record speeds accurately because of the changing vehicle paths through the curve; the manual nature of the surveys would also preclude long survey periods. Therefore using a series of electromagnetic wave beams across the road was suggested as a practical solution for this type of survey. Investigations revealed that red-light optical beams and sensors, which could provide the necessary beam link, were readily available. Customised sensor housings and data collection software were developed to provide the required data.

In selecting sites, a number of factors were identified for possible investigation, where feasible:

- The presence of a curve warning sign (with or without an advisory speed) and the presence of any chevron boards, to identify the incremental effect of each feature.
- The differences between calculated approach speeds, posted advisory speeds, and calculated curve speeds.
- The effect of road and shoulder widths and roadside hazards (e.g. steep gullies) on travel speeds.
- The relative speed profiles of light vehicles (mainly cars) and heavy vehicles (trucks and buses). These were identified by recorded vehicle length.
- Speeds were to be checked where possible in dry/wet and day/night conditions, to identify any adjustment factors made by drivers.
- Sites selected also included some that are identified as being incorrectly posted with too high or low an advisory speed. This enabled us to compare the speed profiles at these sites with sites that are more accurately signed. The results could indicate the relative merit that drivers place on the posted speeds.
- Roughness information was collected for curves to assess its impact on vehicle friction. Considerable rutting or uneven crossfall may cause vehicles to "bounce", affecting their safe curve travel speed.

In all, 27 curves were surveyed, having advisory speeds ranging between 25 and 85 km/h (including three curves without posted speeds). Approximately 20 hours of data was collected at each site. After data cleaning, over 18,700 vehicle speed records were obtained from the sites.

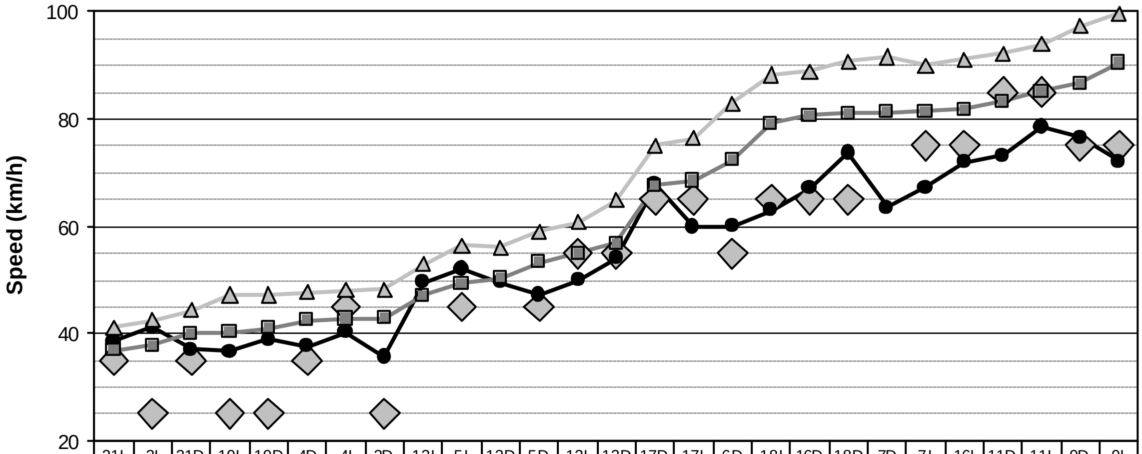
Curve speed prediction using ball-bank indicators, road geometry data and an accelerometer device were also checked using additional drive-over surveys. An accelerometer/gyro-based system was developed that can be fitted to a vehicle and connected to a data logger. This device was then used to continuously record data, (including lateral and longitudinal accelerations, body roll and travel speed) as the vehicle traversed a corner. Software on a connected laptop analysed the data and ultimately derived an advisory speed for the curve.

Four curves were also surveyed using the accelerometer/gyro device. Each curve was also tested using the ball-bank indicator for accuracy and repeatability, particularly at different survey speeds. A number of different surveyors were used to identify any operator biases and three different vehicles (a sedan car, van, and small rigid truck) were also compared. At each site, approximately 36 different combinations of travel speeds, vehicles, and drivers were used. Road geometry data from the curve sites was also used to derive curve advisory speed measures analytically.

Results

Figure 1 summarises the key measurements for each site surveyed, sorted in order of increasing (observed mean) speed. The data points have been named in terms of their site number and direction (increasing/decreasing route position), e.g. 14D, 7I. Posted advisory speeds ("Post Spd") are compared with derived ball-bank speeds ("BB Spd"), observed mean speeds ("Mean Spd") and observed 85th percentile speeds ("85% Spd"). These speed measures have been derived for all free vehicles (i.e. those not travelling in platoons). Because of the good sample sizes observed at each site, the 95% confidence intervals for the observed speeds average only ±0.7 km/h, with a maximum error of ± 1.2 km/h at site 18D.

Figure 1 Summary of Speed Measures at Survey Sites



	21I	3I	21D	19I	19D	4D	4I	3D	13I	5I	13D	5D	12I	12D
Post Spd	35	25	35	25	25	35	45	25	0	45	0	45	55	55
BB Spd	38.6	41.0	37.0	36.7	38.9	37.6	40.1	35.6	49.6	52.0	49.6	47.2	49.9	54.1
Mean Spd	36.9	37.7	40.1	40.2	41.0	42.5	42.7	42.9	47.1	49.2	50.3	53.3	55.0	56.8
85% Spd	41.0	42.4	44.4	47.2	47.2	47.6	48.0	48.3	52.9	56.4	56.1	59.1	60.8	64.9

	17D	17I	6D	18I	16D	18D	7D	7I	16I	11D	11I	9D	9I
Post Spd	65	65	55	65	65	65	0	75	75	85	85	75	75
BB Spd	67.8	59.9	60.1	62.9	67.0	73.7	63.5	67.2	71.9	73.2	78.5	76.5	72.1
Mean Spd	67.7	68.4	72.3	79.2	80.7	81.1	81.2	81.3	81.8	83.3	85.2	86.6	90.4
85% Spd	75.0	76.4	82.9	88.2	88.9	90.7	91.6	89.9	91.1	92.1	94.0	97.2	99.7

Site Number & Direction

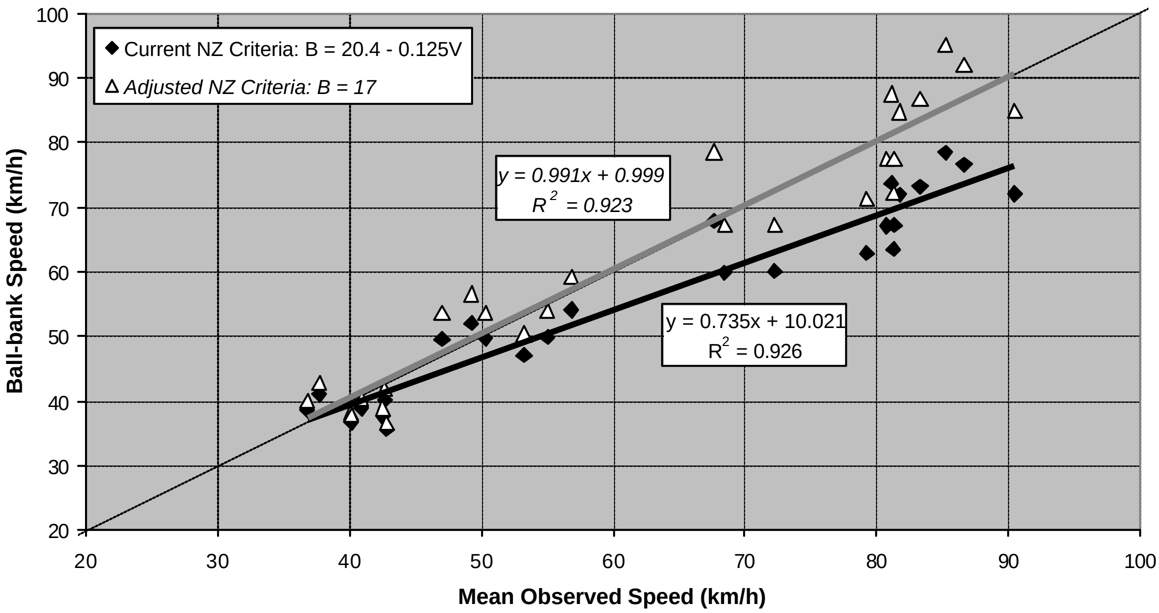
A number of trends are evident. Firstly, posted speeds generally underestimate actual observed operating speeds, particularly at high and low speeds. It is only in some of the mid-range (45-65 km/h) sites that the posted speeds more closely match the operating speeds. Secondly, the derived ball-bank speeds appear to provide a reasonable measure of observed mean speeds up to about 60 km/h. For higher speeds however, there is a disparity of ~10-15 km/h. If it is assumed that the observed mean speeds are reasonable operating speeds then this suggests that the ball-bank speed calculation needs some adjustment whenever the derived advisory speed is greater than 60 km/h.

A comparison between the currently posted advisory speeds and those derived via ball-bank gauge during site investigation shows reasonable agreement, with no ball-bank reading suggesting a posted speed more than 10 km/h different to that currently posted. However, only half of the readings would produce exactly the same (rounded) posted speed, a figure mirrored by the last New Zealand survey (LTSA, 7). There is clearly a pattern of underestimating at low speeds and overestimating at high speeds, which merits further investigation.

Further analysis of the data also found differences in mean speeds of 1-8 km/h between light and heavy vehicles, but no significant effect due to different daylight conditions. No trends were identified in terms of relative sign sizes, the presence of an additional chevron board, or any other more general conspicuity factors noted by the survey team (e.g. vegetation, sight-rails, approach lengths). The relative measured roughness of each site surface was also not a significant factor. These findings suggest that a more complex combination of factors is acting to produce the relative compliance rates at each sites, and that the sample of sites is not sufficiently large enough to identify these factors.

The field studies suggested that ball-bank surveys do not derive sufficiently high enough advisory speeds for higher-speed (>60 km/h) curves. In fact, if the ball-bank derived advisory speeds (V_A) are plotted against the observed mean speeds (as shown in Figure 2, dark points) a fairly flat relationship is produced. The equivalent advisory ball-bank reading, b_A (degrees), was back-calculated for each point (using the current NZ equation) and then various other ball-bank/advisory-speed relationships were tested. It was found that the equation $b_A = 17$ (i.e. with no V_A term) appeared to fit a one-to-one relationship very well (as shown in Figure 2, light points).

Figure 2 **Comparison of Ball-bank Criteria vs Observed Mean Speeds**



The implications of this are that drivers do not change their level of comfort (as represented by lateral acceleration) for different curves. This is contrary to past suggestions that drivers are willing to accept more discomfort at lower curve speeds.

The accelerometer/gyro results suggested that, accurately carried out, both manual ball-bank and automated accelerometer devices can produce reasonably matching advisory speed measures. But a means of "smoothing" the automatically recorded gyro readings may be needed to reduce the lateral acceleration peaks and produce less conservative values. Alternatively some calibration, by comparison with ball-bank surveys at a few test sites, would enable the calculated gyro speeds to be appropriately adjusted.

Determination of advisory speeds using road geometry data also appeared to present no less accurate a method for assessing curves than ball-bank surveys. Where a network or route is being rechecked for sign inconsistencies, a combined approach may be best, whereby road geometry is used first to identify the anomalies in the signs inventory and ball-bank surveys are used to confirm them, thus cutting down the number of sites to check in the field.

Conclusions

The above findings suggest that changes to New Zealand's existing advisory speed system would be necessary to obtain a more accurate method of posting speeds that were appropriate to observed speeds. The biggest problem however in suggesting a change in the speed criteria adopted is the potential safety impacts. Drivers used to travelling more than 10 km/h above posted advisory speeds would be in for a nasty shock if they found a more realistic approach had now been applied to posted speeds. Although public education campaigns could be carried out, invariably the message would not get to everyone, with potentially tragic results.

The last revision to the system, in 1992, was masked by the simultaneous introduction of the new symbolic signs and speed values ending in 5. Without changing the signing system every time we wish to review our speed standards, such an opportunity is not available this time. A possible approach instead is to subtly change the standard by very small increments, causing only a few "borderline" posted speeds to be increased to the next level. Over time this would have the effect of very subconsciously lowering the expectation of drivers to exceed the speed when encountering advisory speeds in general. However to effect a fairly large change in driver expectation (e.g. 10 km/h) will require a number of such changes over a long period of time.

Recommendations

The following items are some of the key recommendations for further investigation or action. Some of them are based on parts of the research not discussed in detail above:

- A standard methodology for carrying out ball-bank survey procedures correctly should be made available for local road practitioners, e.g. in the Manual of Traffic Signs and Markings (MOTSAM).
- The relative safety benefits of curve advisory speed signs should be identified separately from those of curve warning signs, using local crash data.
- Driver education on the dangers of travelling at the same curve speeds in the wet should be promoted.
- The effect of changing curve signing on driver behaviour should be studied. Some sites were identified in this research where the currently signed speed (if any) differed from that measured from field and geometry data. Before and after surveys would be useful where a speed plate was changed, added, or removed. This would eliminate differences between sites surveyed in the current survey.
- A documented road geometry method should be allowed as an alternative for deriving curve advisory speeds in New Zealand. Allowance should also be made for using automated devices instead of ball-bank gauges, provided it can be demonstrated that the device has been properly calibrated.
- Investigate further the merit of non-mechanistic linear curve speed formulae, for example using just approach speed and curve radius to predict curve speed.
- Further tests using the in-vehicle gyro on flat and constantly sloped surfaces could help identify the amount of body roll in typical New Zealand vehicles.
- Guidelines for curve advisory speeds on unsealed roads should be developed, making use of available design friction values. Further research to observe traffic behaviour at a number of unsealed sites is also suggested.
- Guidance should be developed for specific truck-warning signs at sites where the combination of typical speed, radius and superelevation exceed the roll-over threshold for a typical high truck.
- Consider changing the curve advisory speed system to round to posted speeds ending in zero. This could be in conjunction with making a slight change in speed criteria.
- Alternative curve warning devices, such as the road marking countermeasures investigated at Monash and dynamic warning systems, should be trialled here.

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